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SUMMARY REPORT

SPACE STATION MISSION SIMULATION

MATHEMATICAL MODEL

Prepared for the

LANGLEY RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Hampton, Virginia

OPERATIONS RESEARCH SECTION

Fort Worth Division of General Dynamics

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CONTRACT NAS1-5874
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APPROVED

R. A. Gorrell
Group Engineer
Operations Research

Dr. C. B. Moore
Manager of
Operations Research

T. E. Peace
Project Manager

OPERATIONS RESEARCH SECTION
Fort Worth Division of General Dynamics

A B S T R A C T

This report is a summary of the work accomplished under contract NAS 1-5874, the development of a Space Station Mission Simulation Mathematical Model and attendant computer programs.

A brief description of the basic modelling objectives, analyses performed during model development, and a synopsis of study applications to which the model is suited are given.

The results of some problem studies which were conducted during model verification are also given.

CONTRIBUTIONS TO MODEL FORMULATION

The following General Dynamics personnel contributed to the formulation of the model:

Fort Worth Division

F. M. Collins - Cost Analysis
H. R. Darby - Systems Analysis
M. K. Fox - Flight Mechanics
J. J. Gilliland - Cost Analysis
R. A. Gorrell - Technical Support
H. F. Hefley, Jr. - Flight Mechanics
J. L. Howse - Skill Optimization, Experiment Analysis
J. L. Hunter - Computer Programming
J. C. Martin - Station Operations
C. B. Moore - Technical and Management Direction
M. B. Patrick - Computer Programming
T. E. Peace - Project Manager
M. H. Pittman - Computer Programming
J. G. Srygley - Scheduling, Model Integration
G. G. Tharp - Cost Analysis
G. E. Voyles - Preliminary Requirements Model
L. J. York - Logistics, Mathematical and Statistical Analysis

Convair Division

R. S. French - Human Factors Data
C. D. King - Life Support System Data
B. D. Newsom - Physical Fitness Data
P. H. Selby - Human Factors Data

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1.0 INTRODUCTION

A Manned Orbital Research Laboratory (MORL) system concept, capable of fulfilling many space-related research and development objectives, has been derived through previous studies. A need was thus generated for a computerized, mathematical model which would serve as an analytical, managerial tool for efficient implementation of a MORL or other programs. The model enables the analyst to perform a spectrum of integrated studies concerning the interacting program elements illustrated in Figure 1. Thus, the likelihood of decisions without consideration of the total system or mission will be reduced. Comparative studies of these elements will generally be performed through control of input by (1) exercising provisioned model options, (2) user supplied problem data, or (3) changing the base line library data stored within the model.

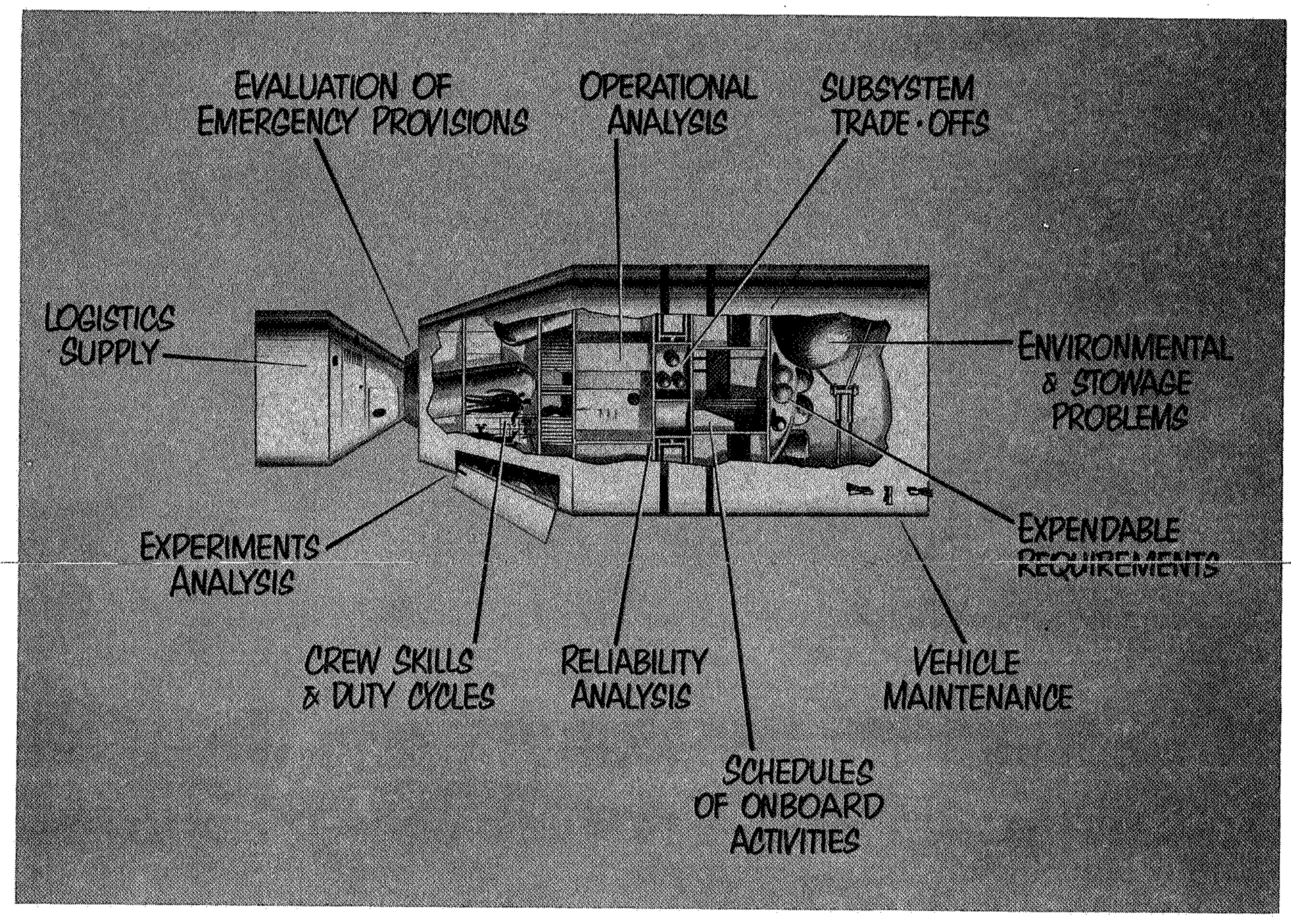

FIGURE 1 TYPICAL MODEL APPLICATIONS

2.0 OBJECTIVES

The key objectives and provisions which were factored into the model are depicted in Figure 2. The model has been structured for easy up-dating and flexible operation necessary for including

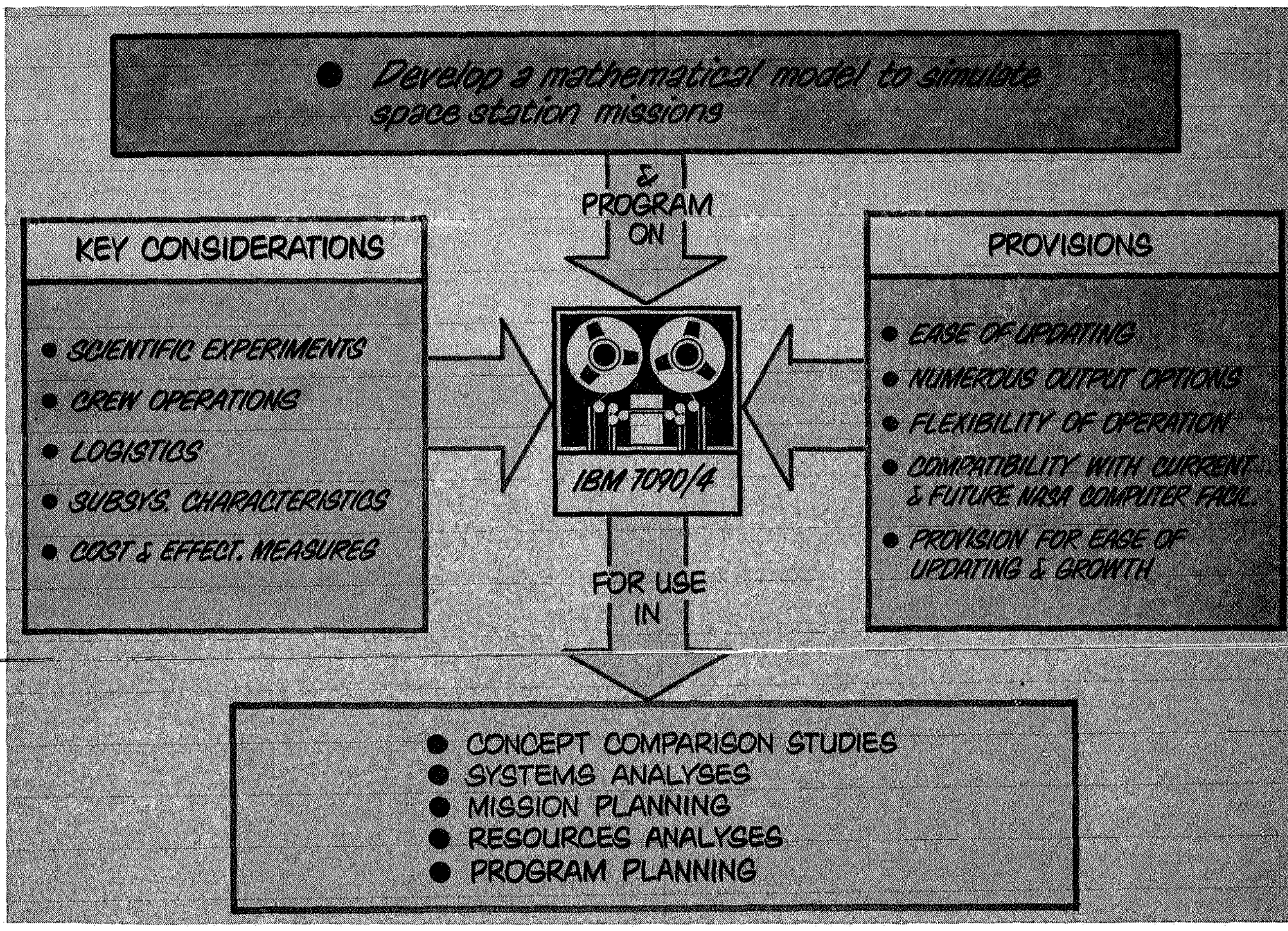

FIGURE 2 PROGRAM OBJECTIVES

new data and new concepts as the space station program evolves. In addition, the particular needs of the model user were considered by providing numerous options for reducing outputs irrelevant to the analysis being made.

3.0 STUDY PLAN

The relationships among the major task areas required to accomplish the previously described objectives are shown in Figure 3. Phase I was devoted to developing the basic model structure and accomplishing the analytical work necessary to the detailed structuring during Phase II. Tasks completed during Phase II included the development of detail logic diagrams and library data, as well as integration, programming, check out and implementation of the model at the NASA Langley Research Center.

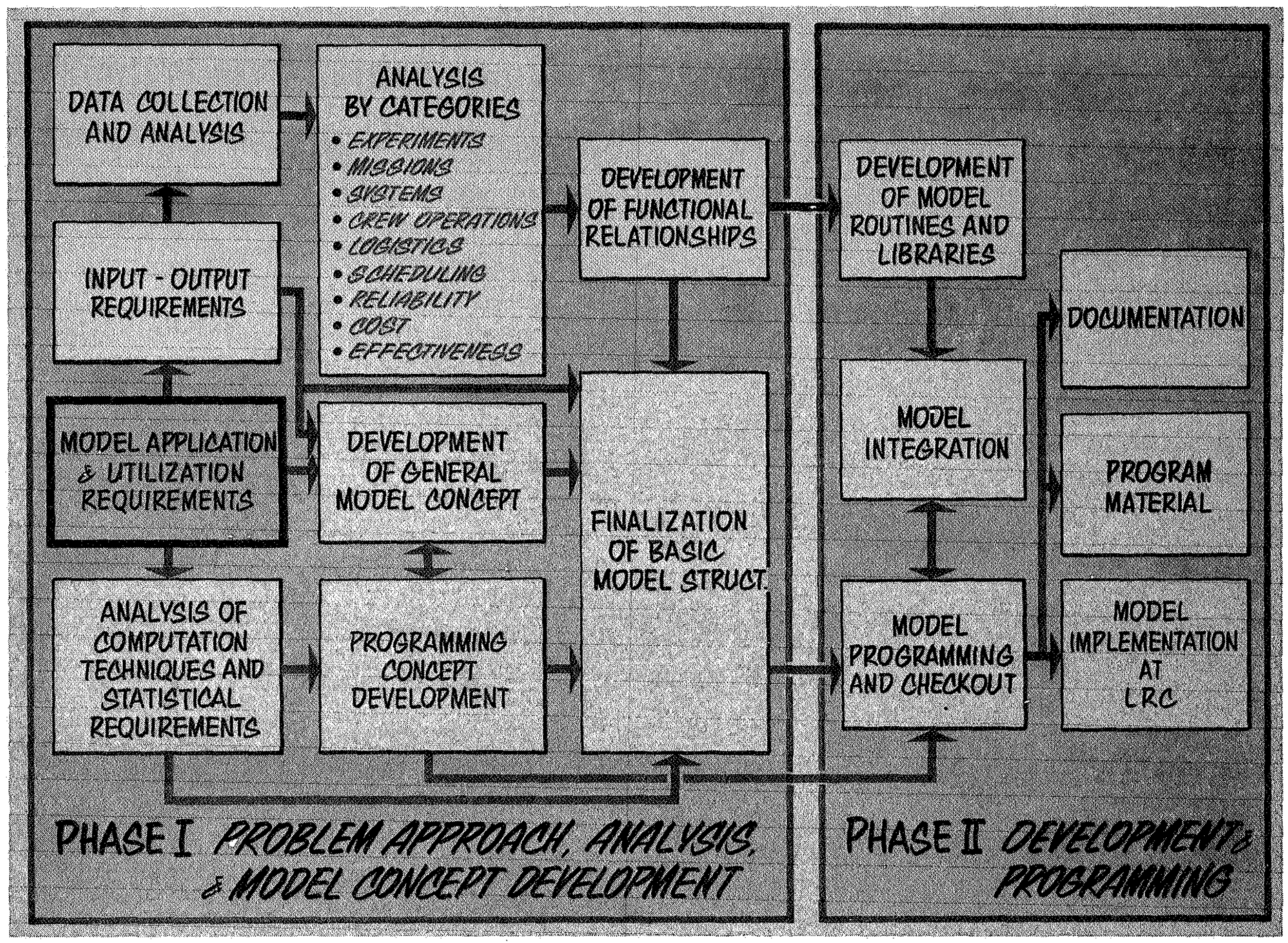

FIGURE 3 MODEL STUDY PLAN

4.0 M O D E L C O N C E P T

As shown in Figure 4, the model consists of three computer programs, each applicable to a different phase of the operation. Economy of run time and user time is realized because of the ability to select levels of refinement through choices of independent computer programs to be used. In the early stages of mission plan evaluation, a Preliminary Requirements Model (PRM) can be used to make gross evaluations of mission parameters for assessing the feasibility of mission concepts and determining initial mission requirements. As the mission concept becomes better defined, a more refined mission plan can be developed through the use of a Planning Mode of the model to generate and evaluate a deterministic mission plan. Finally, the Simulation Mode provides a means for determining the effects of contingencies on this mission plan. The sequence may be terminated at the level of detail dictated by the problem. When used in sequence, the Preliminary Requirements Model will generate inputs for the Planning Mode which in turn will generate inputs for the Simulation Mode. A brief description of the functions, structural concepts and interrelations

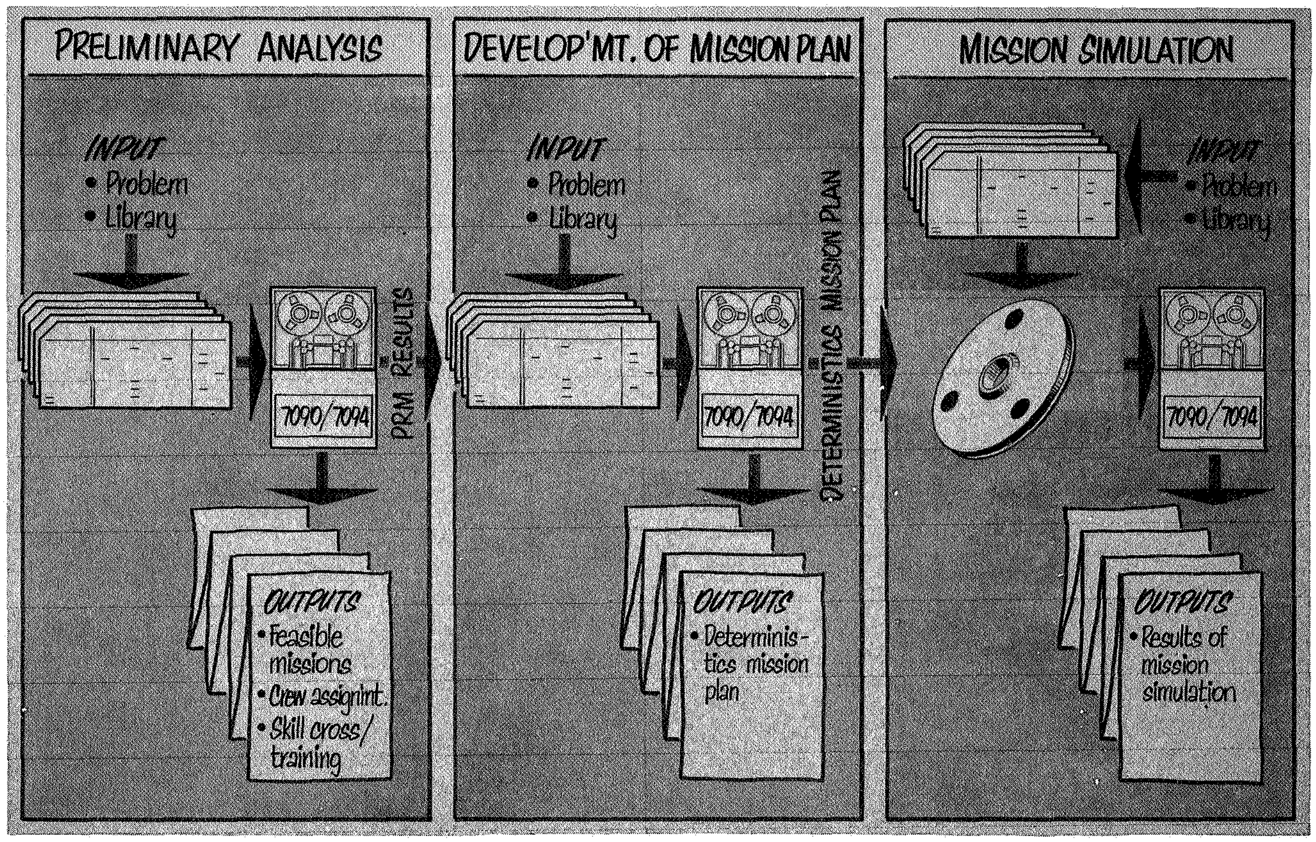

FIGURE 4 SPACE STATION MISSION SIMULATION
MATHEMATICAL MODEL CONCEPT

of these portions of the overall model is as follows:

Preliminary Requirements Model (PRM): The primary function of the PRM is to assist in screening unacceptable programs by performing gross evaluations to obtain an initial estimate of the mission requirements. In addition, it serves as an aid for selecting crews based on the experimental program to be accomplished during a launch interval and the skill mixes possessed by condidate crewmen (Ref. Section 5). As shown in Figure 5, the PRM is structured to cycle through the crew rotation launches until the end of the mission. Payload excess capacities are used for experimental equipment. At the users option, libraries describing experiment assignments, associated crew descriptors, and the logistics profile can be prepared for input to the Planning Mode. The computer run time usually varies between three and six minutes for typical case problems.

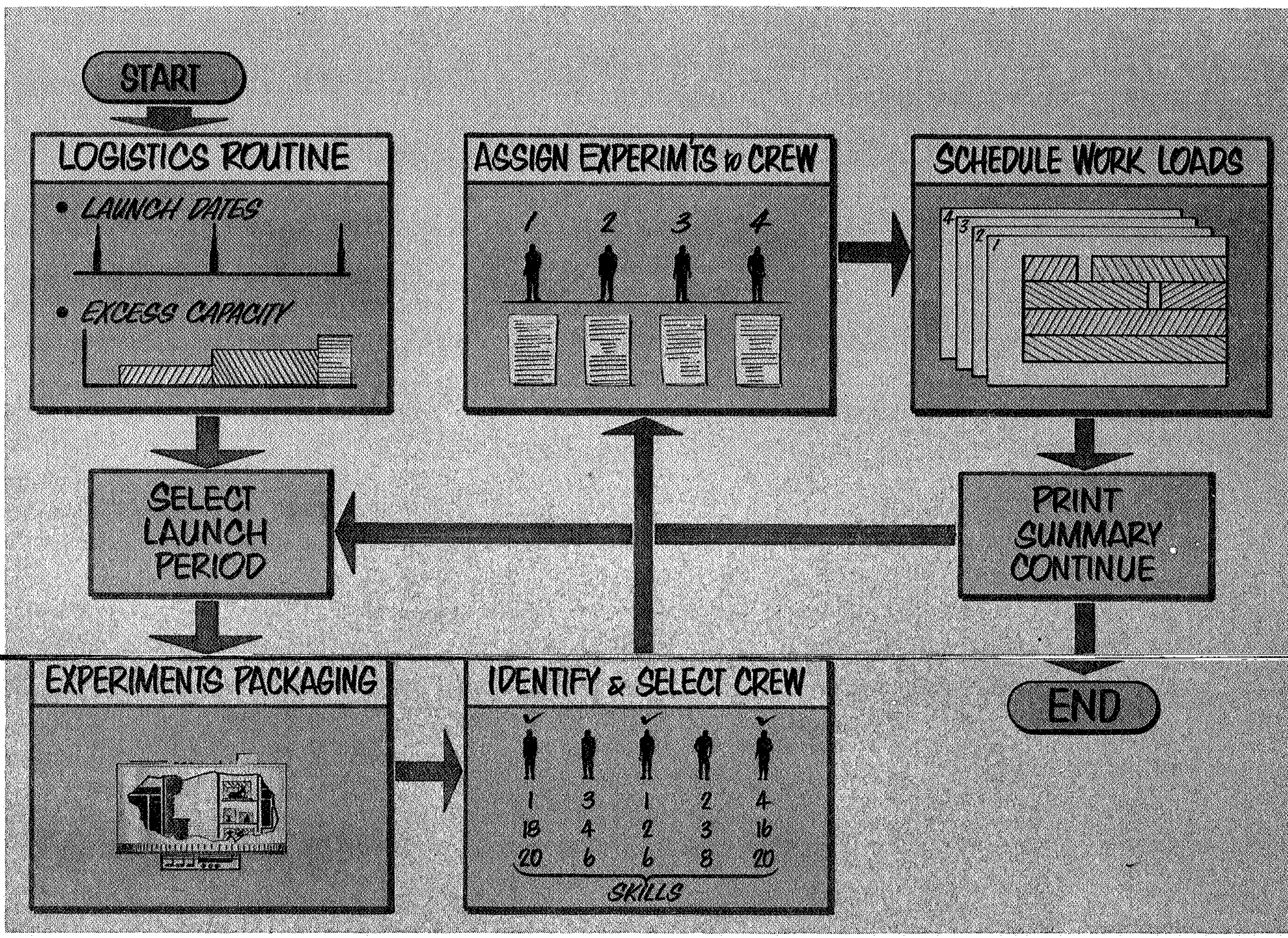

FIGURE 5 PRM OPERATIONAL SEQUENCE

<u>Planning Mode</u>: The Planning Mode was designed to develop a mission plan analogous to one which would be developed prior to an actual mission. The Planning Mode is deterministic, using expected values for system parameters and an entire mission of up to 540 days is viewed as a single problem. Its operational sequence is relatively simple as shown in Figure 6 but offers considerable sophistication over the PRM. Initially, the station expendable requirements are determined by a station operations routine. Next, the logistics schedule is established by use of a logistics routine. A scheduling routine schedules the station keeping and personal requirements and then the experiments until the remaining resources or experiments are exhausted. An evaluation routine provides a summary of the mission requirements, cost, and effectiveness. The input has been simplified by providing much of the data in prepared libraries. Only data defining mission calendar start date, duration, orbital parameters and the prepared libraries to be used are required problem data.

The computer run time varied from 8 to 25 minutes for test problems. When desired, tapes of the mission plan may be generated for direct input to the simulation mode.

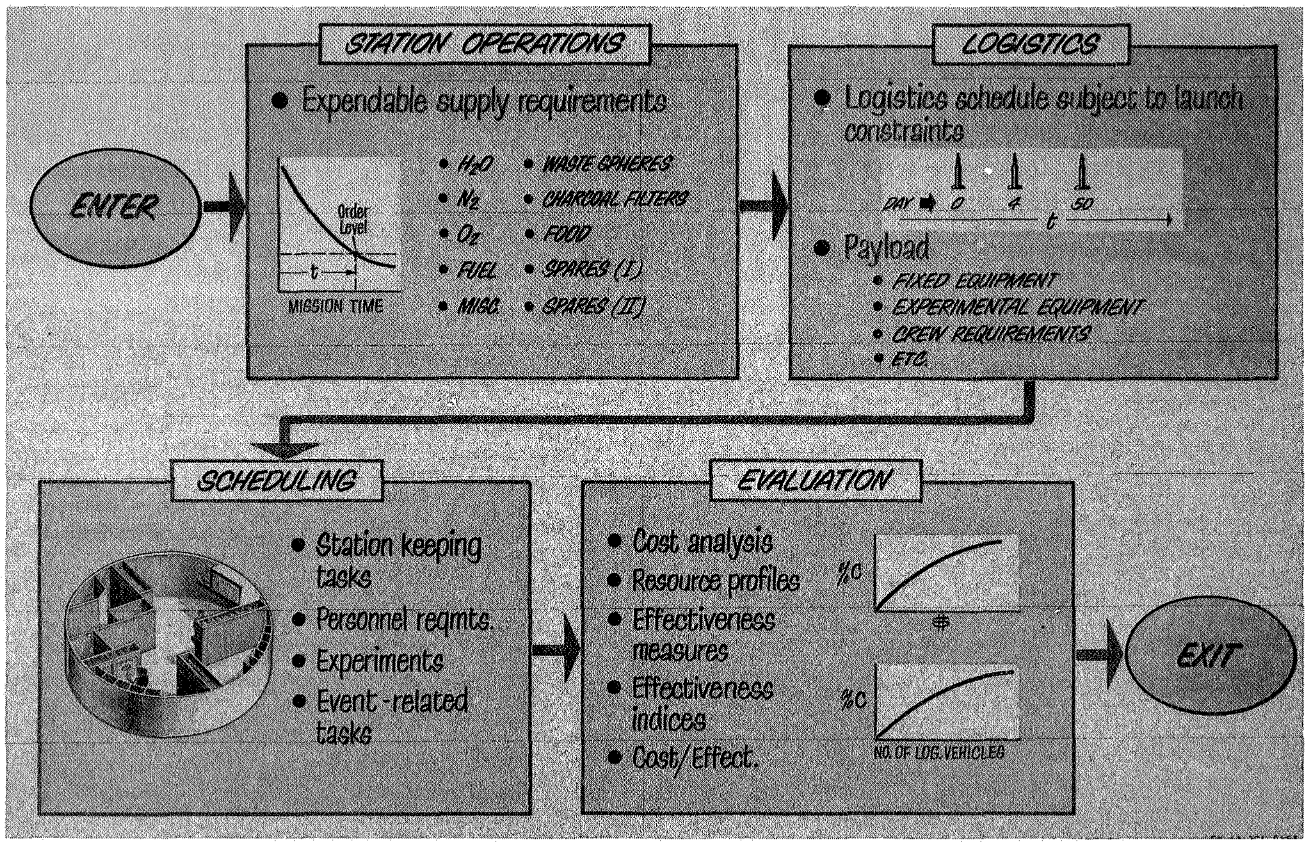

FIGURE 6 PLANNING MODE

Simulation Mode: The purpose of the Simulation Mode is to provide a means for determining the effect of contingencies on the mission plan generated by the Planning mode. As shown in Figure 7, a random events generator determines the times of occurrence and durations of probabilistic events which are in turn transferred to an event controller, the central coordinator for the Simulation Mode. As described in Section 10, event-to-event simulation is utilized. The event controller advances to each event, processes it, and proceeds to the next event in time. This process continues until the arrival of a scheduled crew vehicle (provided the mission has not been aborted prior to this time). Thus, in the Simulation Mode each interval defined by crew arrivals constitutes one problem, whereas the Planning Mode examines the entire mission. These intervals may be connected, however, providing information about the total mission. It is necessary that the Planning Mode be run prior to the Simulation Mode in order to prepare a tape containing the mission plan data. By generating most of the input information in this manner in conjunction with the Simulation Modes libraries, only five problem data cards are required. There is significant variation in computer run time from problem to problem since the numbers and types of events processed are random. Experience to date indicates that run times between 20 and 45 minutes may be expected.

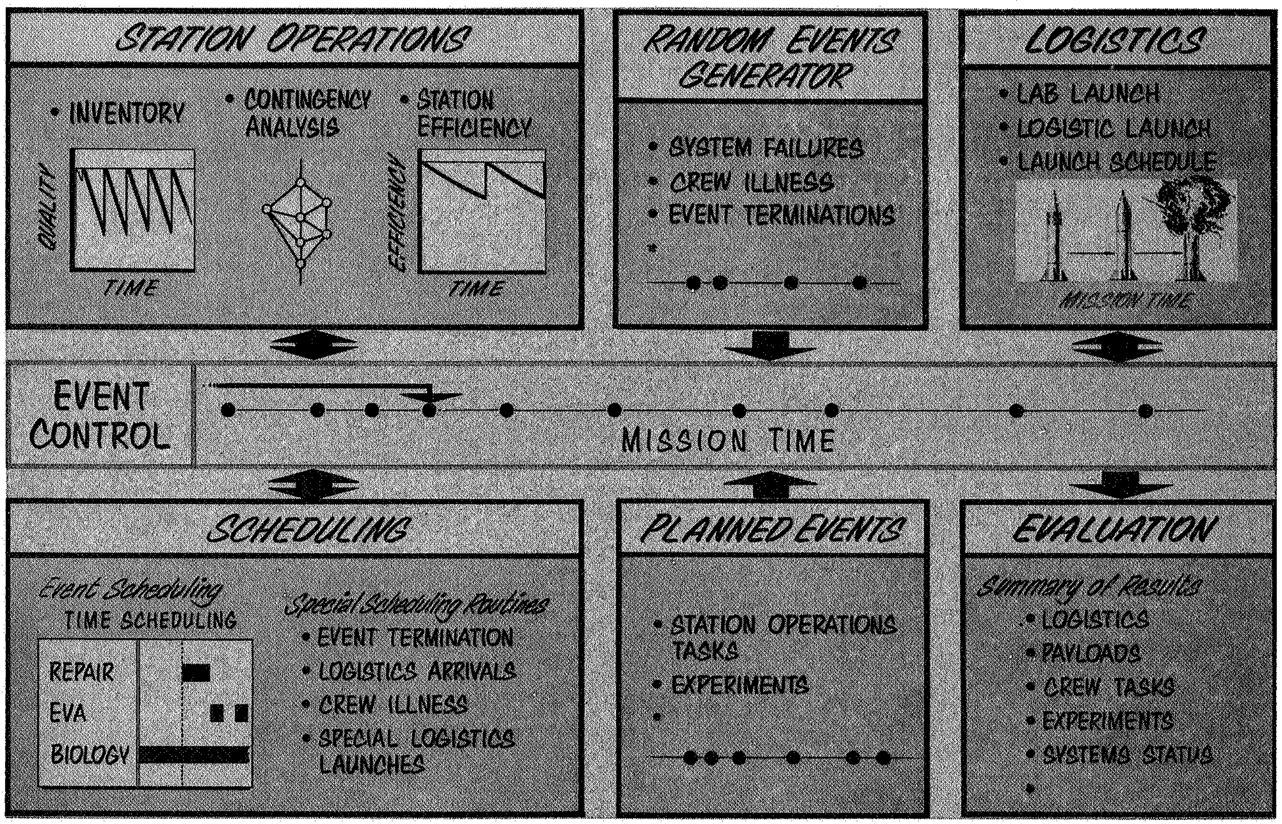

FIGURE 7 SIMULATION MODE

5.0 CREW ANALYSIS

Crew related factors affect all phases of model simulation and, hence, appear throughout the model and its associated libraries. The selection of crews on the basis of skills and skill cross-training considerations, along with the initial crew task assignments, are performed in the PRM using the procedure shown in Figure 8. The PRM input consists of a set of skill mix arrays which represent the types of astronauts, based upon skill cross-training considerations, from which to select crews for the mission. The procedure then selects, for each launch period, the astronauts which yield the most effective experimental accomplishment. This selection takes into account the conditions imposed by the crew

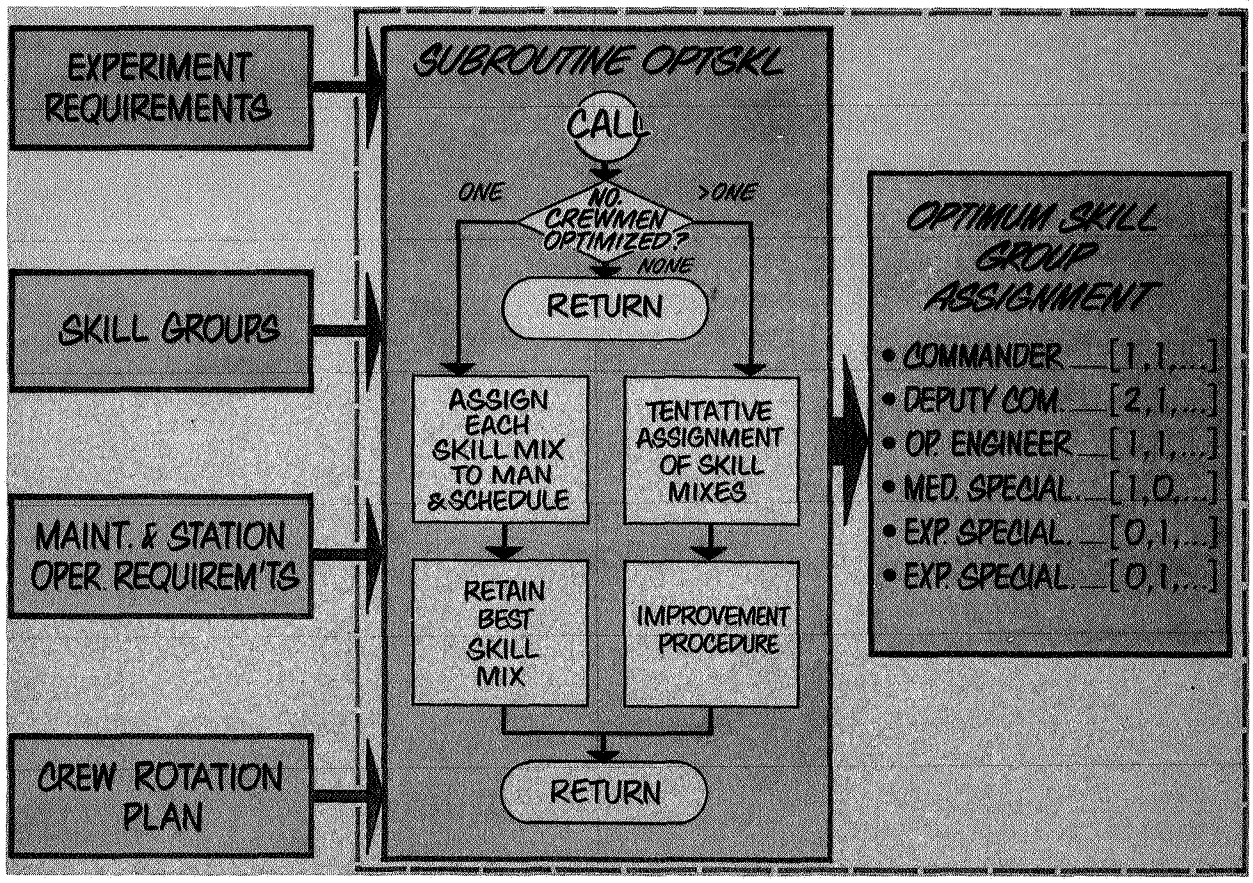

FIGURE 8 SKILL OPTIMIZATION PROCEDURE

rotation profile and the station operations demands. Task-time factors may be used in any of the model programs to adjust man-hour requirements whenever assignments are made to alternate crewmen who perform at lower proficiencies.

A more elaborate management of crew related factors is performed in the Simulation Mode. Consideration is given to the probabilistic task completion times, occurrence of three degrees of illness, selection of crews for unscheduled repairs, monitoring of crew safety and crew status, and extended shift length under certain considerations.

The model has the capability to treat crew sizes up to nine men. For determining the cross-training requirements for each crewman, twenty skill types and proficiency factors have been included. Crew staytime is controlled by the input crew rotation profile.

6.0 E X P E R I M E N T S   A N A L Y S I S

The baseline set of scientific experiments proposed for MORL was reviewed and analyzed, first, to determine those characteristics (descriptors) which should be used to describe the experiments in the modeling process and, second, to obtain a set of experiments, coded for model input and representing the scientific activity during a typical mission. The overall analytical process is illustrated in Figure 9. It was found that a total of 32

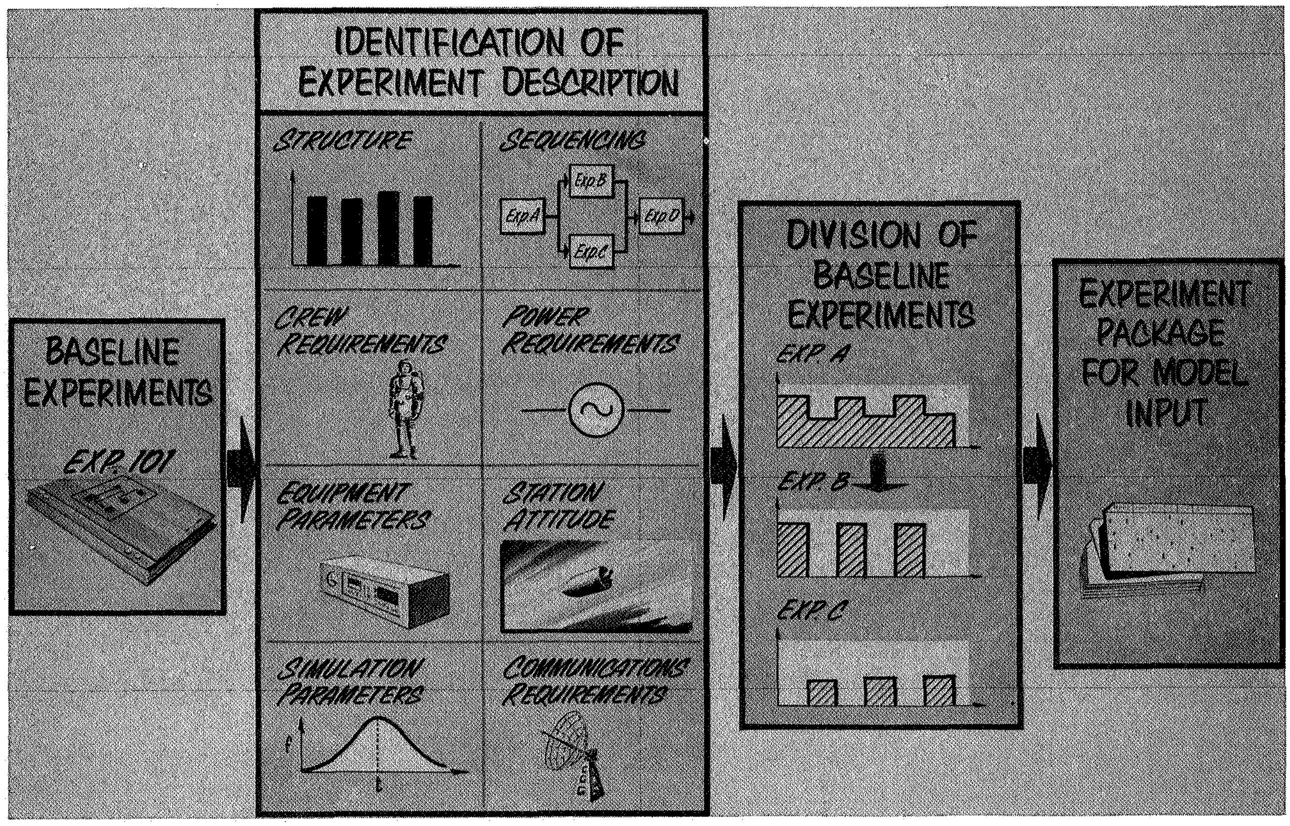

FIGURE 9 EXPERIMENT ANALYSIS

descriptors would be sufficient to provide an accurate characterization of a broad spectrum of experimental activity. However, a number of these experiments could not be coded for model input as a single experiment. In this case, a successor-predecessor mechanism permitted these experiments to be divided and coded as two or more experiments.

A total of 131 experiments were coded and furnished with the model. The same coding procedure can, however, be applied by the model user to prepare other experiments for processing by the model.

7.0 LOGISTICS ANALYSIS

The logistics routine is used to incorporate the effects of a specified logistics system into the mission operations and, subsequently, to evaluate the impact of logistics systems upon the cost and effectiveness parameters. This objective is accomplished by simulating critical operations associated with logistics support. As shown in Figure 10, the logistics routine accepts dynamic launch

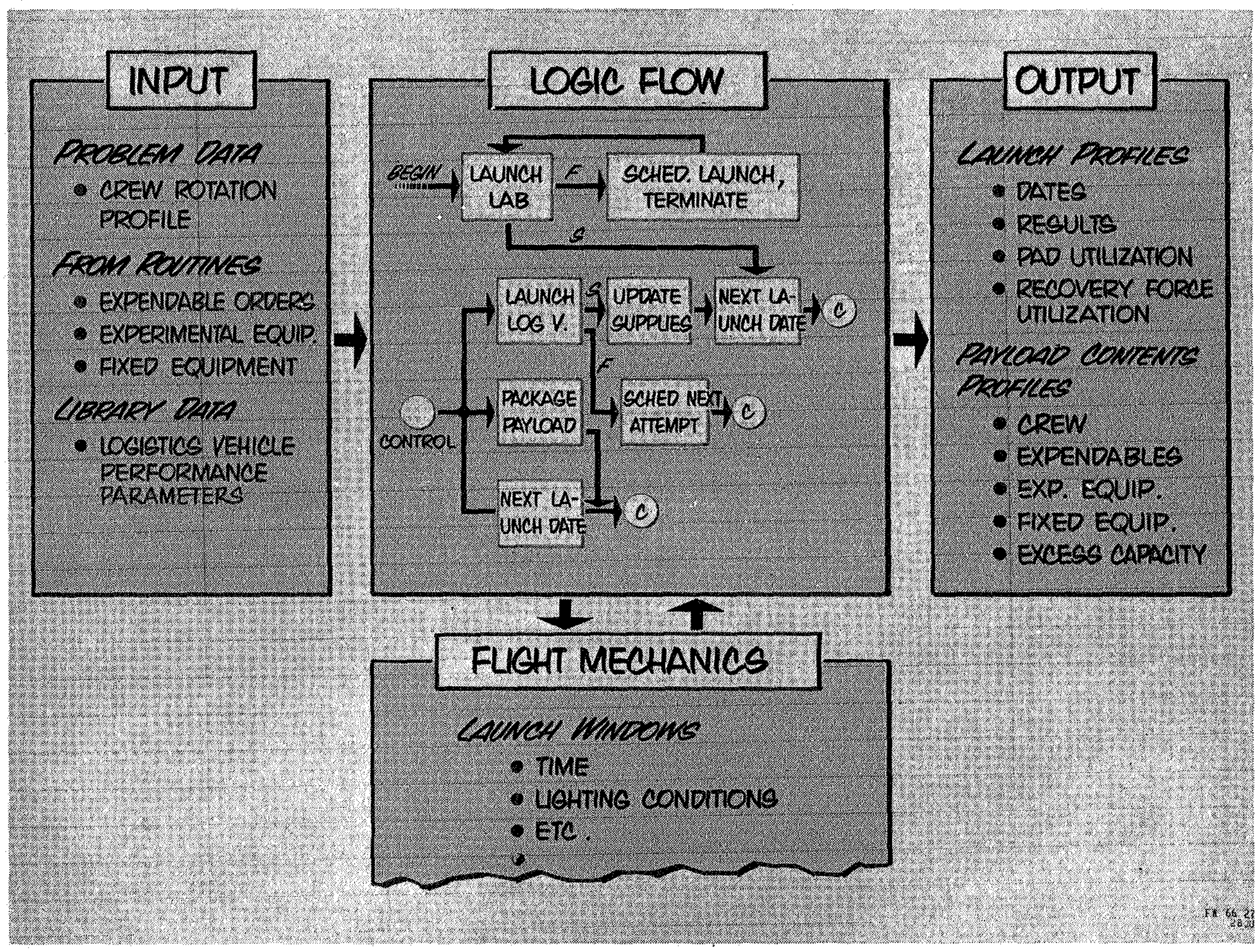

FIGURE 10 LOGISTICS ROUTINE BASIC CONCEPT

requests from the space station and, subject to the constraints of the system and its launch requirements, acts to satisfy these requests. As assessment of the logistics system's ability to satisfy the station's request and the cost of the logistics requirements are provided in order that an effectiveness evaluation may be made.

The logistics routine was developed to simulate operations of a logistics system consisting of a launch vehicle, a multimission cargo module, and a crew carrier with its associated service pack.

The support system consists of a launch complex with a variable number of launch pads and a down-range recovery system with a variable number of deployable forces. The structure of the logistics routine is such that numerous other concepts, such as advanced carriers, can be evaluated by supplying the appropriate library data.

8.0 SCHEDULING OF EVENTS

The scheduling of events into a time ordered mission plan is the function of the scheduling routine. The general approach to scheduling has been to schedule events to fit into discrete time intervals and, although a 24-hour time interval is currently being used, the model is constructed so that the time interval can be reduced. Data currently being used do not justify scheduling on an interval smaller than an 8-hour shift.

The primary objectives to be accomplished by the scheduling routine are shown in Figure 11. In addition, scheduling of random events in the Simulation Mode permits (1) determination of probable deviation from initial plans, (2) specific case studies, (3) formulation of special procedures, and (4) use of the model as a training aid. The process of scheduling these random

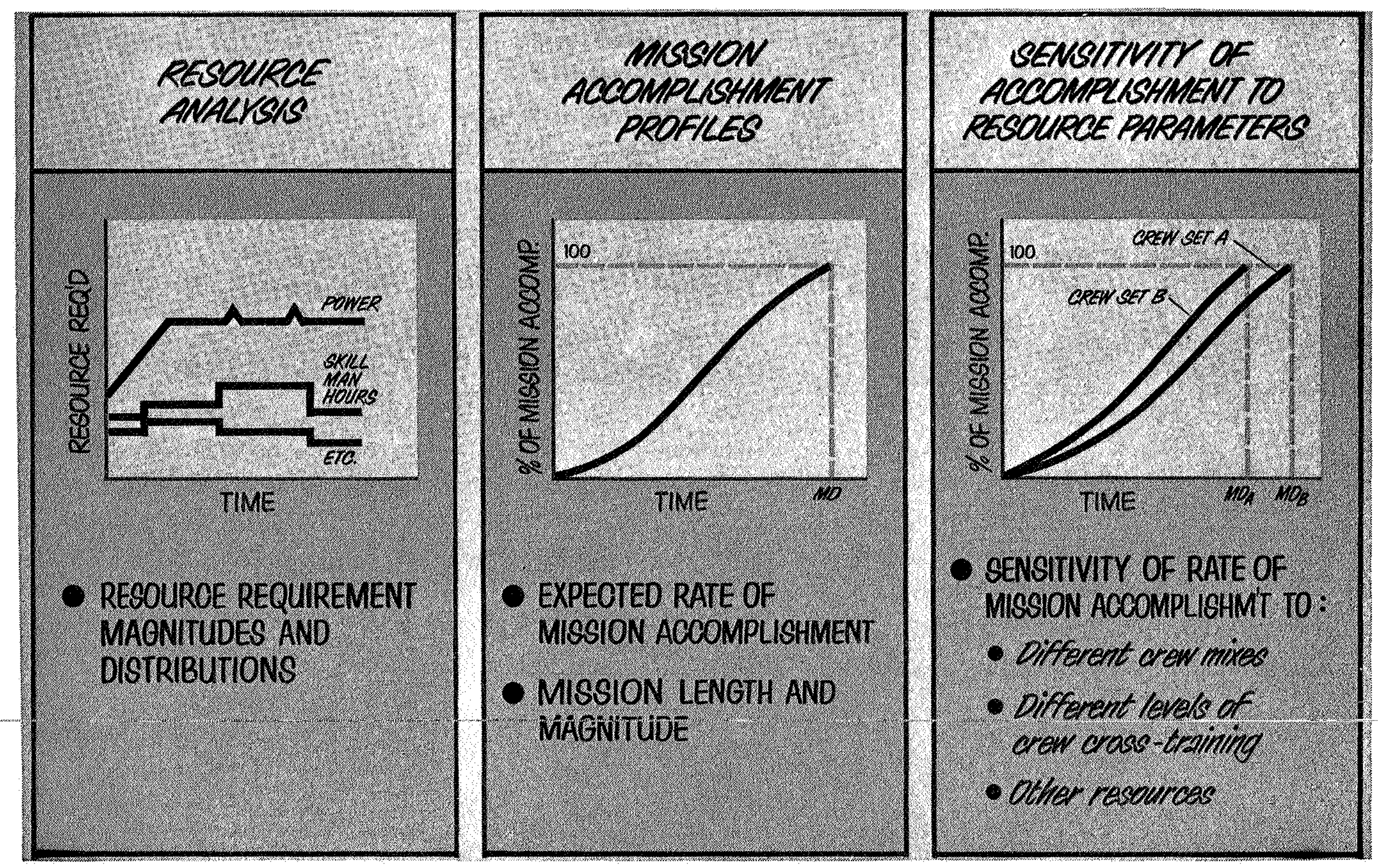

FIGURE 11 SCHEDULING OBJECTIVES

(contingency-related) events and subsequent rescheduling of any interrupted events is illustrated in Figure 12.

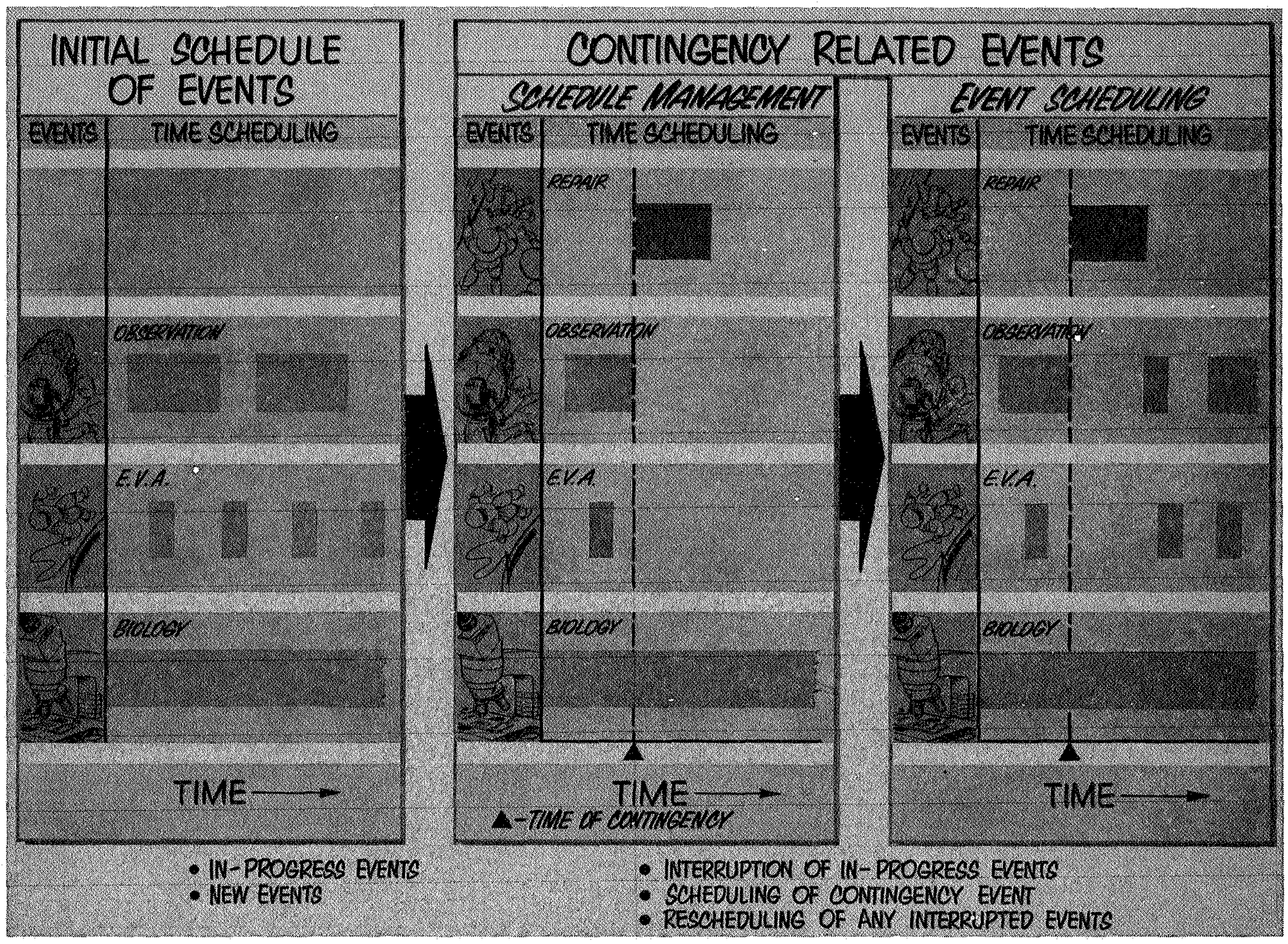

FIGURE 12 SCHEDULING

9.0 STATION OPERATIONS

The purpose of the station operations routine is to determine the portion of on-board resources required to support the station. These resource requirements include laboratory subsystem loading, crew utilization, and logistics supply. When these requirements have been satisfied, the remaining resources can be used for support of the experimental programs. A large portion of the task in developing the routine was the preparation of libraries for the MORL systems. These libraries contain such items as replacement levels, repair time distributions, failure rates, down time constraints, resources available for experiments, etc. These libraries may be easily up-dated by changing the appropriate data cards.

The basic concept of the station operations routine is illustrated in Figure 13. In the Planning Mode, the station operation routine's major functions are (1) to maintain an inventory of the expendable supplies on board the laboratory and (2) to plan their resupply requirements. In the Simulation Mode,

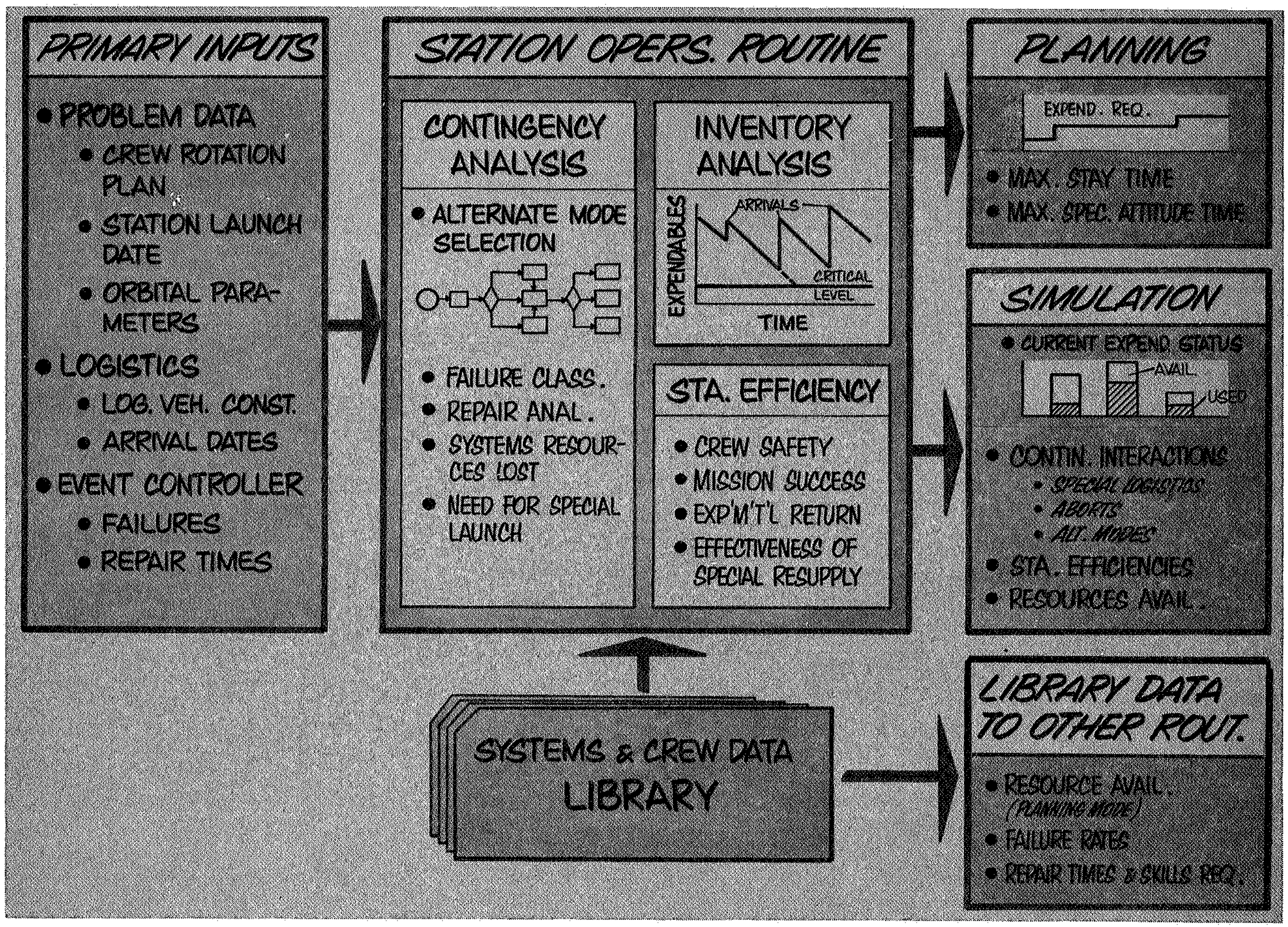

FIGURE 13 BASIC CONCEPT OF STATION OPERATIONS ROUTINE

the routine performs several additional functions to process contingency events. In processing a system failure, adjustments are made in the station status to reflect loss in resources; then, appropriate action is initiated to restore the system to its original operating condition.

10.0 SIMULATION OF PROBABILISTIC EVENTS

An analysis of probabilistic phenomena and methods of simulating these phenomena was made. There are two basic methods, event-sequencing and time-slicing for constructing a digital simulation model. These are illustrated in Figure 14. Using the time-slicing method, the computer is programmed to observe the system status at regular fixed intervals of time and considerable computer time can be spent observing intervals in which there was no change in system status. In the event-sequencing method of simulation, the computer is programmed to proceed directly from one event to the next, ignoring those intervals of time in which there is no change in status. Because of its shorter tun time and precision, the event-sequencing method was selected for the Simulation Mode of the model.

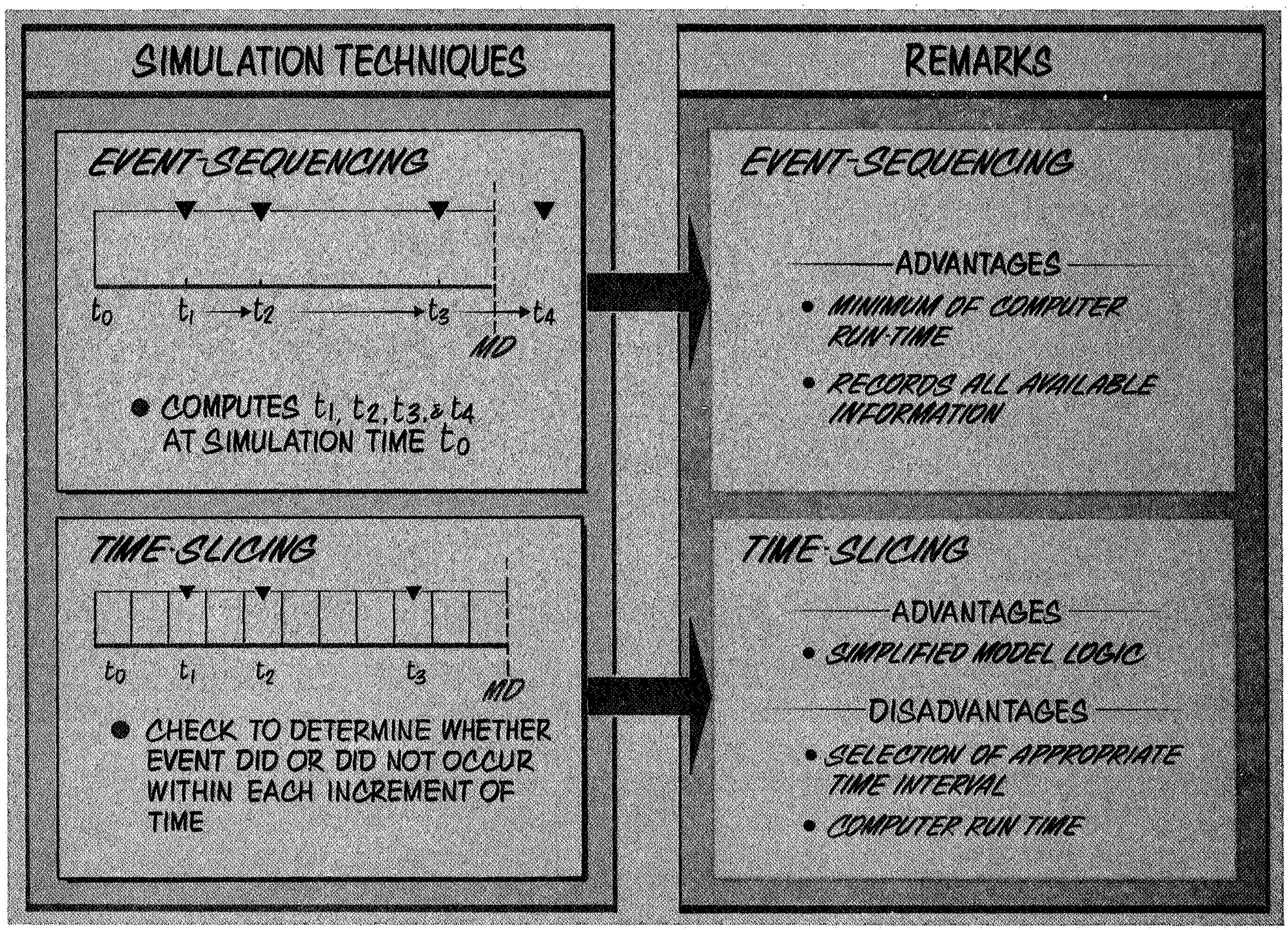

FIGURE 14 SIMULATION TECHNIQUES

Two types of events must be treated by the model and can be classified as either fixed or random. The former are those events whose time of occurrence can be expressed deterministically and are used in developing the program plan in the Planning Mode. Random events are those whose time of occurrence are probabilistic. The origin of such events are shown in Table 1.

TABLE 1 ORIGIN OF RANDOM EVENTS

EXPERIMENTS	SYSTEMS	CREW RELATED AND SPECIAL EVENTS
Duration Failures (Premature Termination)	Failures Repair Times	Crew Illness Station Operation Task Times Solar Flares Meteoroid Punctures

11.0 MISSION EVALUATION

The complexity of a space station program precludes the selection of a single effectiveness parameter for mission evaluation. In such a complex program, an overall evaluation requires the consideration of a multiplicity of effectiveness measures (two of which are shown in Figure 15). To provide this evaluation capability, a special routine, the evaluation routine, was developed

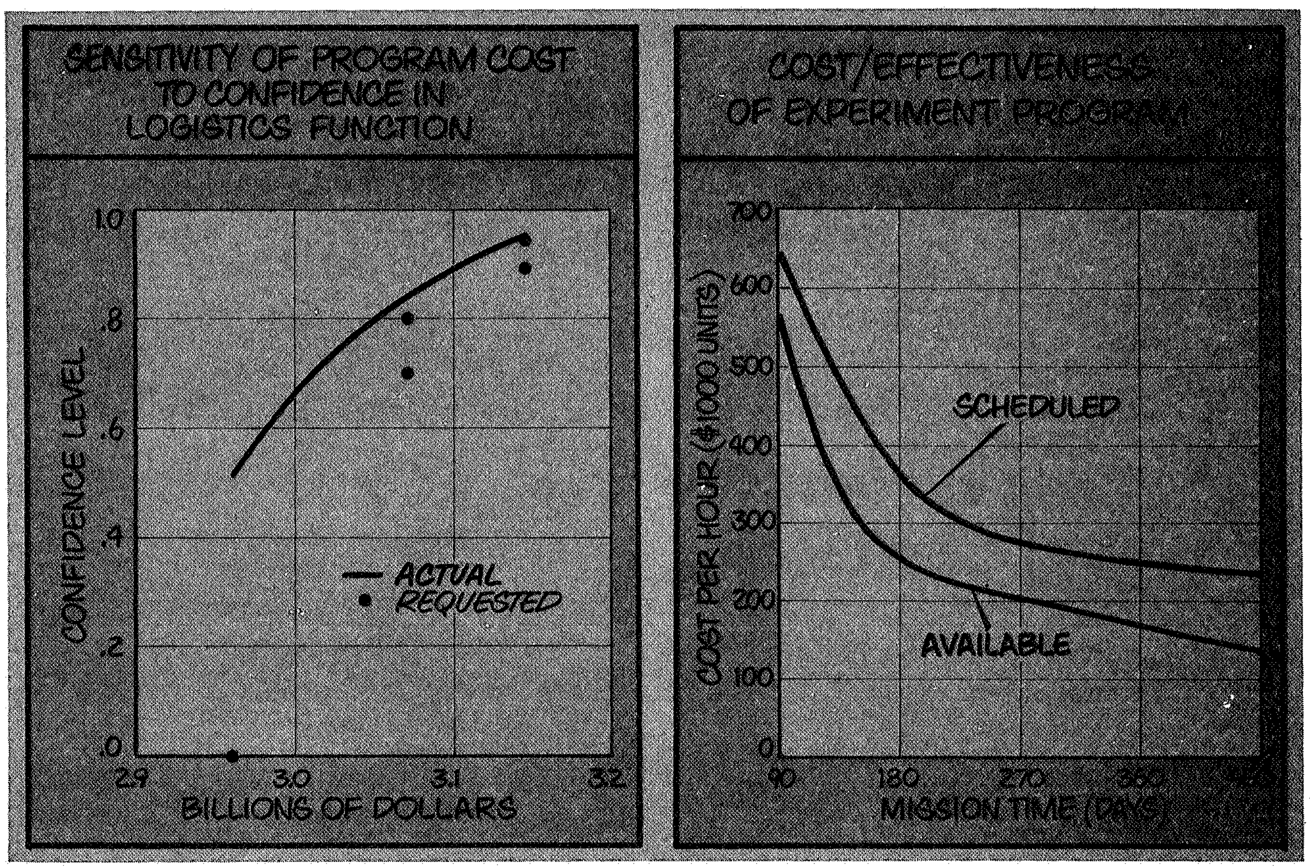

FIGURE 15 COST EFFECTIVENESS VS MISSION TIME

for the Space Station Model. This routine provides a lengthy summary of the accounting measures required for mission evaluation. This includes both resource requirements such as number of logistics shots, total program cost, etc., and mission accomplishments such as experimental man-hours provided, pounds to orbit, etc. The program cost, resource requirements, and effectiveness measures are presented separately and in various combinations of cost and effectiveness indicies.

12.0 TYPICAL CASE STUDIES

During model development numerous runs were made for check out. This section presents some of the results in order to illustrate its utilization capability. The models described in Section 3.0 are capable of servicing a broad spectrum of study problems. In most cases the model user may obtain the desired output by his regulation of input data or in moderate changes in library data. More extensive preparation would be required, of course, if the problem dictated the preparation of an entirely new library such as a completely new experiments package. The large number of program options available in the PRM (see Figure 16) make it a useful tool for studying various

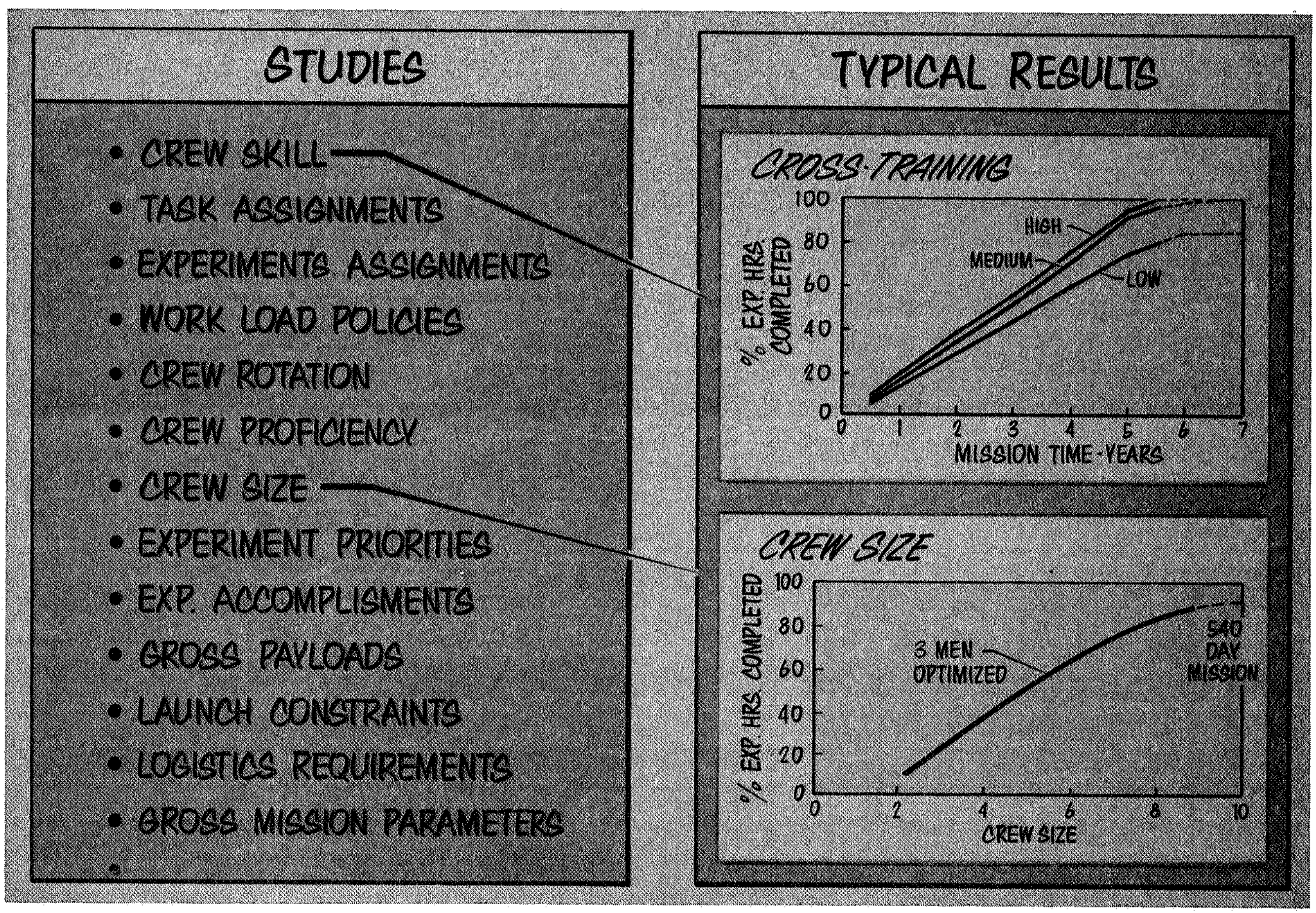

FIGURE 16 PRELIMINARY REQUIREMENTS MODEL STUDIES

aspects of earth-orbital missions. Although the modeling techniques used in the PRM are less refined than those used in the Planning Mode, the shorter running time and simpler data requirements make the PRM more convenient to use in cases when gross results are desired or during early stages of mission planning when data is relatively inexact.

The Planning Mode is suited to a wide range of studies involving logistics requirements, crew analyses, resource analyses, and mission evaluation. Results for three typical studies are indicated in Figure 17. The data for these studies was obtained from a run of the Planning Mode in which the mission duration was 450 days, the crew size was 6, and an experiments package consisting of 131 experiments was used.

The Planning Mode has extensive output of effectiveness measures and utilization efficiencies, which make it particularly suited to problems involving comparison between mission plans.

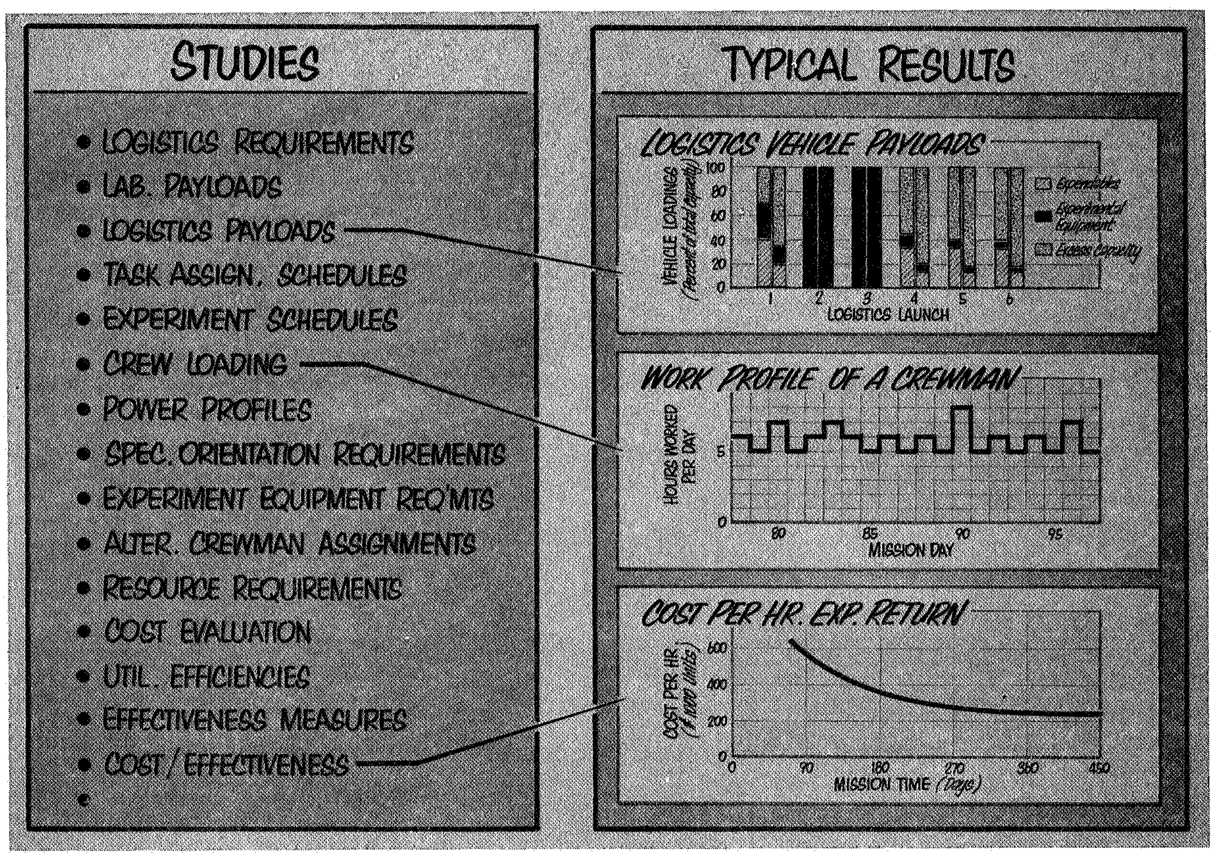

FIGURE 17 PLANNING MODE STUDIES

Events whose occurrence may be expressed probabilistically are accommodated by the Simulation Mode. The impact of system failures, crew illnesses, longer (or shorter) than expected task times, etc., may be viewed in a resulting mission history, which may be compared to a mission plan developed prior to simulation. Some examples are shown in Figure 18 and were taken from a checkout problem in which four system failures and one minor illness occurred during the first

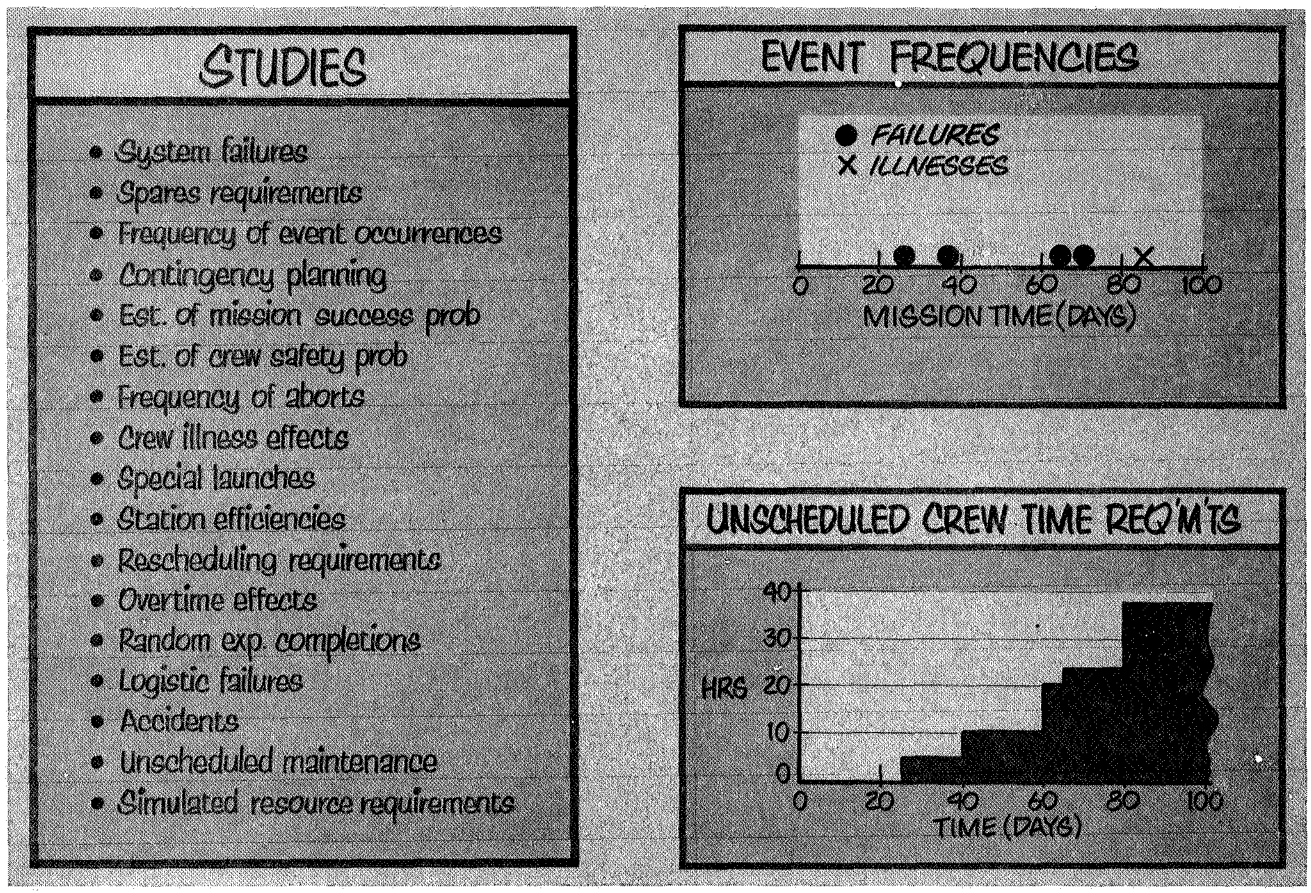

FIGURE 18 SIMULATION MODE STUDIES

90 mission days. As a result of these events, some 38 hours of unscheduled crew time was required.

An important function incorporated into the Simulation Mode is the ability to evaluate the station status and call for special launches as necessary. These unscheduled launches obviously have a significant influence on the program effectiveness and the model has been designed to carefully evaluate other courses of action, or provide choices to the discretion of the user by problem input options, before a special launch is requested. Hence, the Simulation Mode will be a valuable tool for training and studying the causes of any special launches.

13.0 PROGRAM ACCOMPLISHMENTS

Figure 19 presents a summary of the work accomplished under contract NAS 1-5874. The required analyses, model structure formulation and attendant computer program developments were accomplished in accordance with the study objectives. After check-out of major program paths, the programs were inplemented at the NASA Langley Research Center.

After the major model program paths were exercised, the Preliminary Requirements Model and the Planning Mode were additionally tested with selected case problems to further verify their utility on typical problems.

Serviceability in the future has been assured by structure concepts such as the extensive use of libraries which can be easily up-dated or replaced if desired.

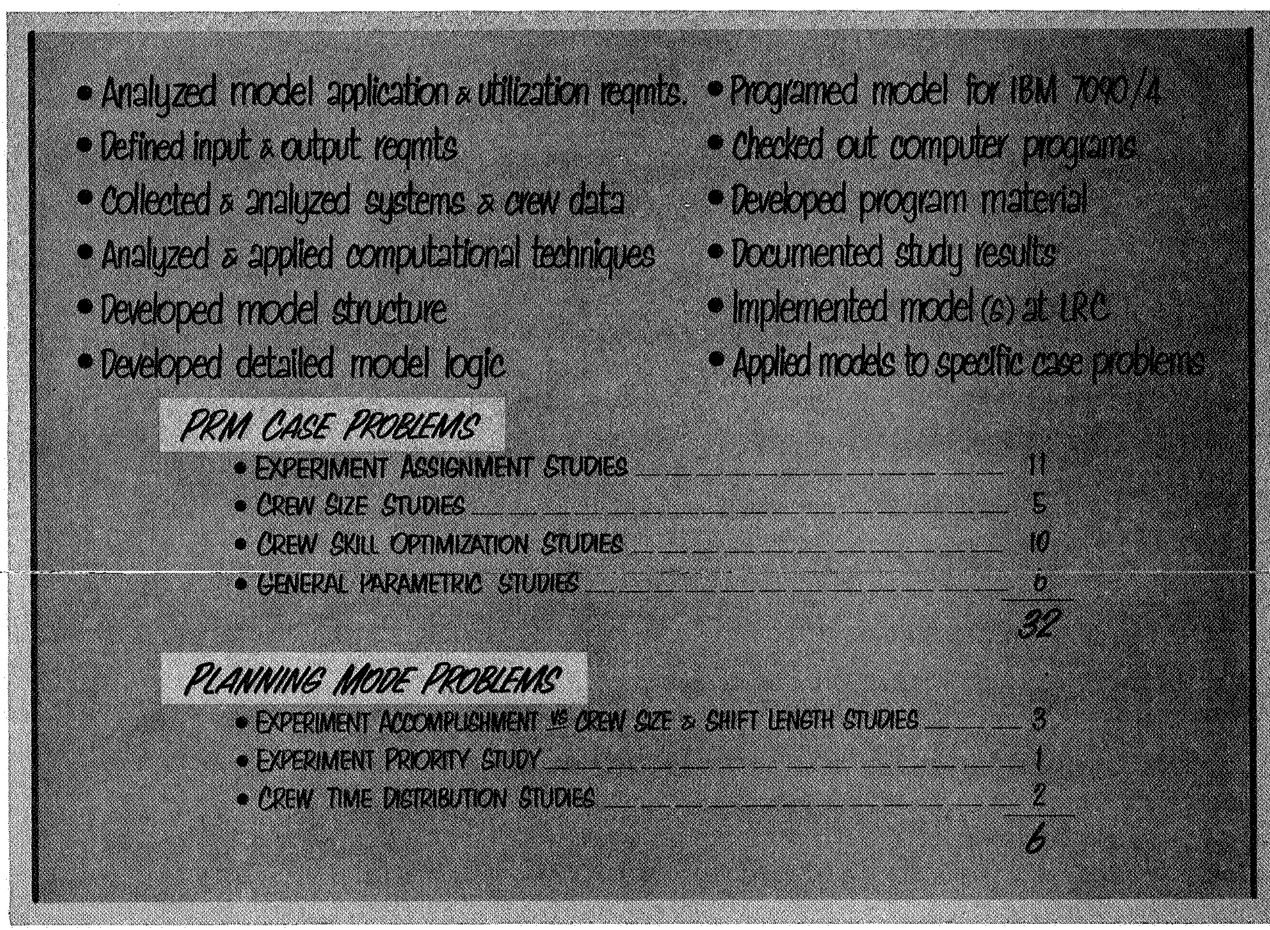

FIGURE 19 PROGRAM ACCOMPLISHMENTS

A synopsis of space station studies for which the model is adapted is presented in Figure 20. Since the model treats the space station system complex as an entity, integrated studies of the various factors indicated can be made. Thus, by using the model as an aid, the user can make decisions concerning the behavior and control of these factors in the proper mission or total system context. In most cases a particular study will not require utilizing the entire model. Therefore, the response time can be minimized by using only those portions actually needed. In addition, numerous options have been provided to omit irrelevant detail from the output.

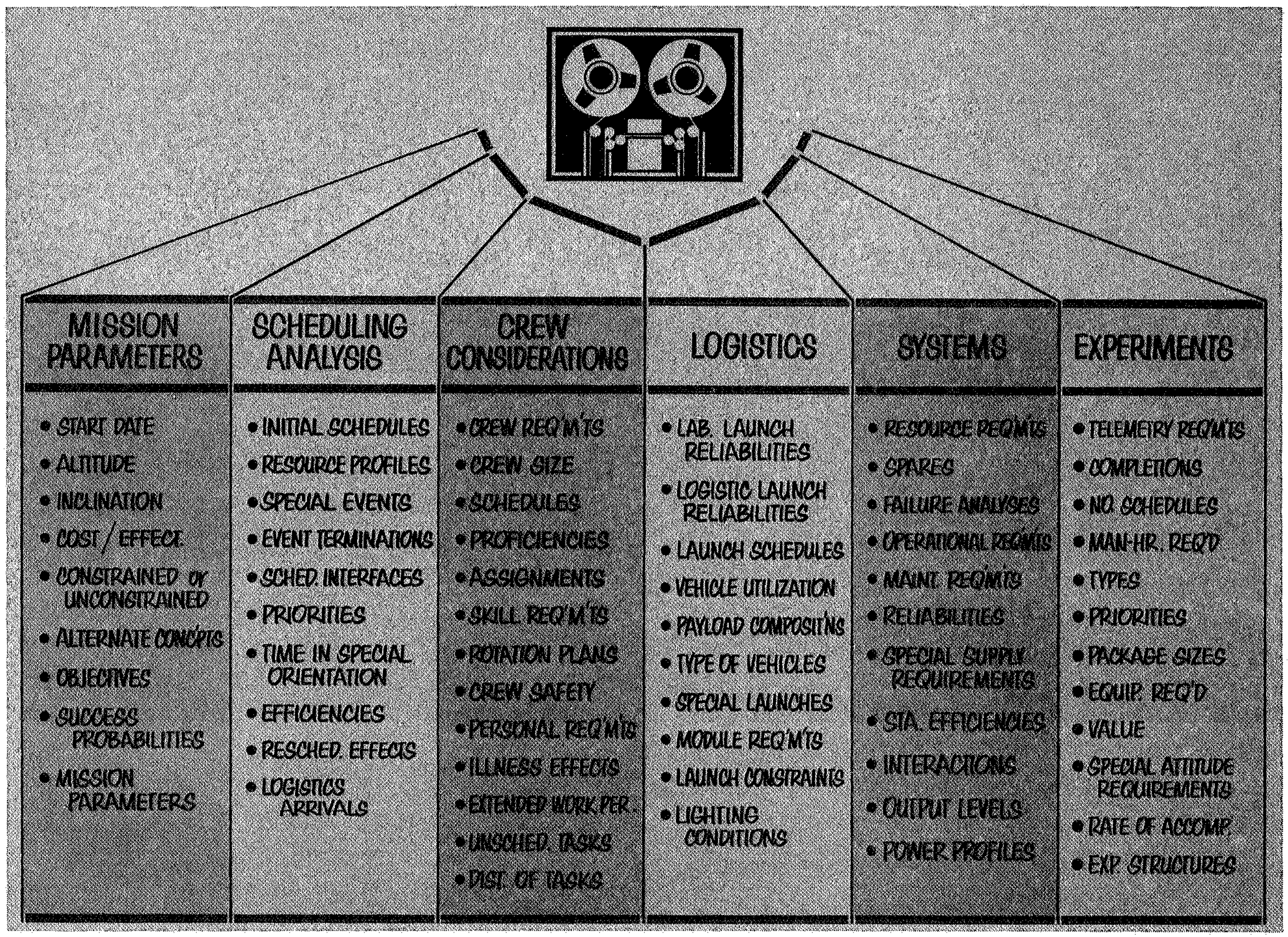

FIGURE 20 SPECTRUM OF MODEL STUDIES